Oxford Cambridge and RSA

Friday 9 June 2023 – Morning

A Level Physics B (Advancing Physics)

H557/02 Scientific literacy in physics

Time allowed: 2 hours 15 minutes

You must have:
- a clean copy of the Advance Notice Article (inside this document)
- the Data, Formulae and Relationships Booklet

You can use:
- a scientific or graphical calculator
- a ruler (cm/mm)

Please write clearly in black ink. **Do not write in the barcodes.**

Centre number						Candidate number				

First name(s) ______________________________

Last name ______________________________

INSTRUCTIONS
- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- **Use the Insert to answer questions in Section C.**
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION
- The total mark for this paper is **100**.
- The marks for each question are shown in brackets **[ ]**.
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **24** pages.

ADVICE
- Read each question carefully before you start your answer.

SECTION A

1 Digestion is an example of an activation process. The energy required for a particular molecule to break apart is 1.2×10^{-19} J.

(a) **(i)** Calculate the Boltzmann factor for this process.

Human body temperature = 310 K

Boltzmann factor = ... **[1]**

(ii) Explain how an individual particle can gain sufficient energy to complete a reaction when the energy required is far greater than the average energy of the particles in the reaction.

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.... **[2]**

The presence of an enzyme increases the Boltzmann factor of the process by a large amount.

(b) **(i)** Explain why this change to the Boltzmann factor affects the rate at which the digestion reaction takes place. Include a description of the information the Boltzmann factor gives about the individual particles involved in an activation process.

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.... **[3]**

(ii) The enzyme increases the Boltzmann factor at 310 K to a value of 6.7×10^{-7} by reducing the activation energy required for the reaction.

Calculate the activation energy of the reaction in the presence of the enzyme.

activation energy = ... J **[3]**

2 A ‘T-shirt cannon’ fires a wrapped T-shirt from the ground into the spectators sitting at a height of 10 m above the ground as indicated in **Fig. 2.1**.

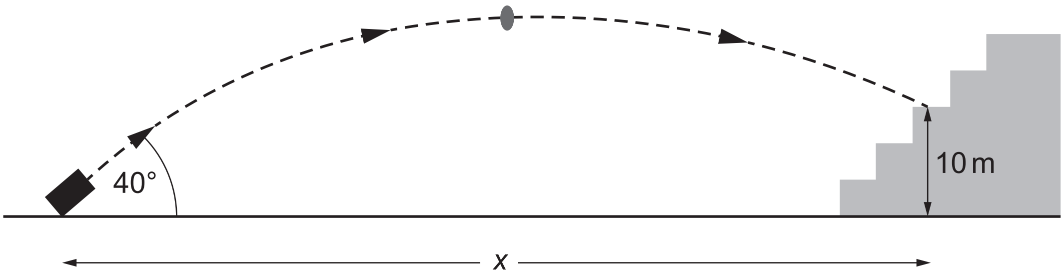

Fig. 2.1 (not to scale)

(a) (i) The velocity of the shirt when it leaves the cannon is 30 m s^{-1} at an angle of 40° to the horizontal. Ignoring the effects of air resistance, show that the highest point reached by the shirt is less than 20 m vertically above the cannon. Assume the shirt is fired from ground level.

[2]

(ii) Calculate the horizontal distance x between the cannon and the place where the T-shirt landed in the spectators.

horizontal distance = ... m **[3]**

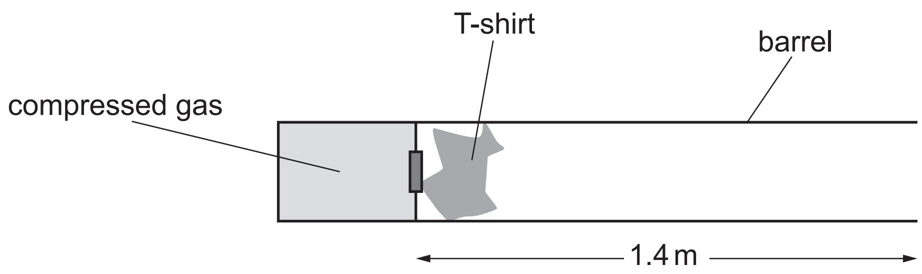

Fig. 2.2

(b) The wrapped t-shirt is accelerated by a release of compressed gas into the barrel of the cannon. The barrel is 1.4 m long as shown in **Fig. 2.2**.

Calculate the average force exerted on the T-shirt as it accelerates through the barrel.

mass of shirt = 0.50 kg

force = ... N **[2]**

(c) The barrel has a uniform radius of 0.05 m. When the compressed gas is released the pressure on the left side of the T-shirt is 4.0×10^4 Pa greater than atmospheric pressure. Calculate the initial force on the T-shirt and explain why it is greater than the average force.

initial force = ... N

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.... **[3]**

3 A sample of argon gas is very slowly compressed in a piston as indicated in **Fig. 3.1**.

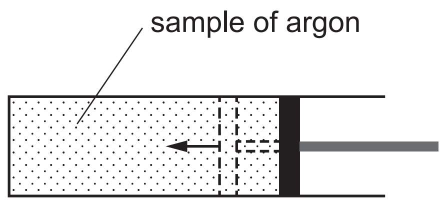

Fig. 3.1

(a) Draw graphs on **Fig. 3.2a** and **Fig. 3.2b** showing how the pressure P of the gas varies with the volume V and how the pressure varies with $\frac{1}{V}$. Assume that the temperature of the gas does not change during compression.

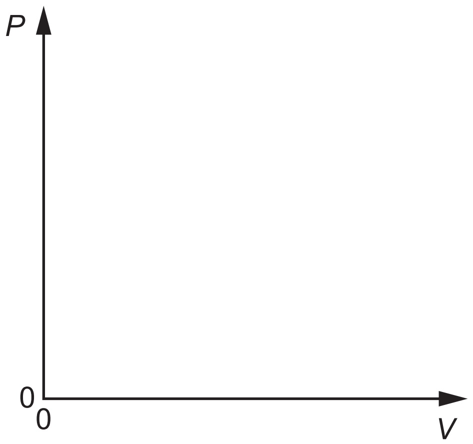

Fig. 3.2a

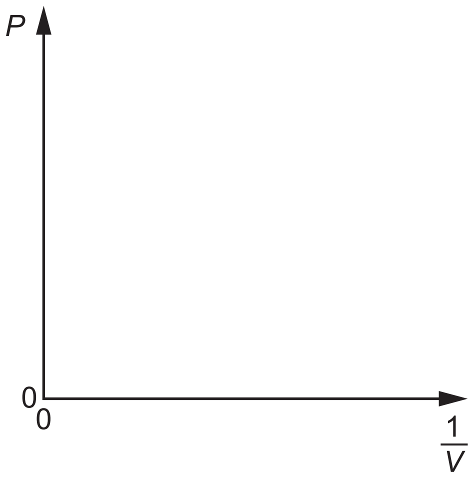

Fig. 3.2b

[2]

(b) The temperature of the gas is 298 K. The mass of an argon atom is 6.6×10^{-26} kg.

Show that the root mean square speed of the atoms is about $430\,\text{m}\,\text{s}^{-1}$.

[3]

(c) This part of the question considers how the behaviour of the gas changes if the piston is moved in quickly.

An argon atom moving at +430 m s^{-1} strikes the face of the piston which is moving at –1.5 m s^{-1} as represented in **Fig. 3.3**.

Fig. 3.3

(i) The collision between the atom and the piston is elastic. Explain why the velocity of the gas atom is –433 m s^{-1} after the collision.

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.... **[2]**

(ii) Describe and explain how the behaviour of the gas would change if the gas were compressed more quickly.

You may use equations and refer to your graphs in **Fig. 3.2a** and **3.2b** in your explanation.

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.... **[3]**

SECTION B

4 **Fig. 4.1** shows apparatus that demonstrates standing waves in air. The two speakers, separated by about 2 metres, are connected to the same signal generator, producing coherent oscillations.

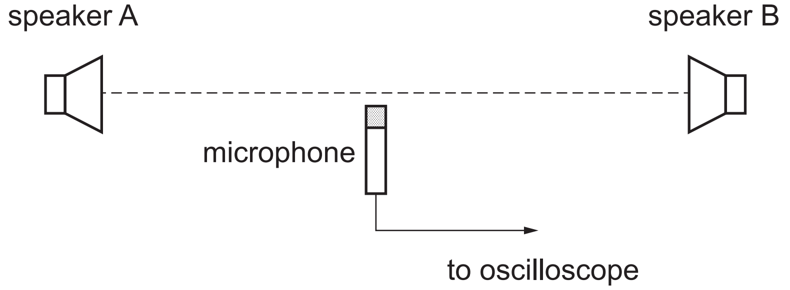

Fig. 4.1

(a) Explain how standing waves are set up in between the two speakers and how this is observed.

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.... **[3]**

(b) **(i)** The signal generator vibrates the speakers at a frequency of 3.00 kHz. The microphone detects positions of minimum amplitude (nodes) separated by 5.60 cm.

Calculate the velocity of sound in air.

velocity of sound = ... $m\,s^{-1}$ **[1]**

(ii) A student suggests that a more accurate determination of the velocity of sound could be made if the distance between several nodes was measured instead of the distance between adjacent nodes. Explain the student's reasoning.

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.... **[3]**

(c) The electron in a hydrogen atom can be modelled as a standing wave in a box of length equal to that of the diameter of the atom as indicated in **Fig. 4.2**.

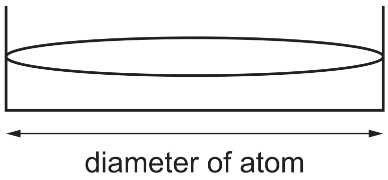

Fig. 4.2

(i) Show that the momentum of an electron in a box of length 2.4×10^{-10} m is about 1.4×10^{-24} kg m s^{-1}.

[1]

(ii) Calculate the kinetic energy of the electron.

kinetic energy = ... J **[2]**

(iii) Calculate the potential energy of an electron at a distance of 1.2×10^{-10} m from a proton.

potential energy = ... J **[2]**

(iv) Use your answers to **(ii)** and **(iii)** to explain whether or not the electron would escape from the proton at this distance and explain how an estimate for the minimum size of a hydrogen atom can be calculated.

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.... **[3]**

5 This question is about using alpha particles in radiotherapy. **Fig. 5.1** shows a graph of the number of ion-pairs formed by an alpha particle travelling through air. After 70 mm the alpha particle captures two electrons to become a helium-4 atom and ionisation stops.

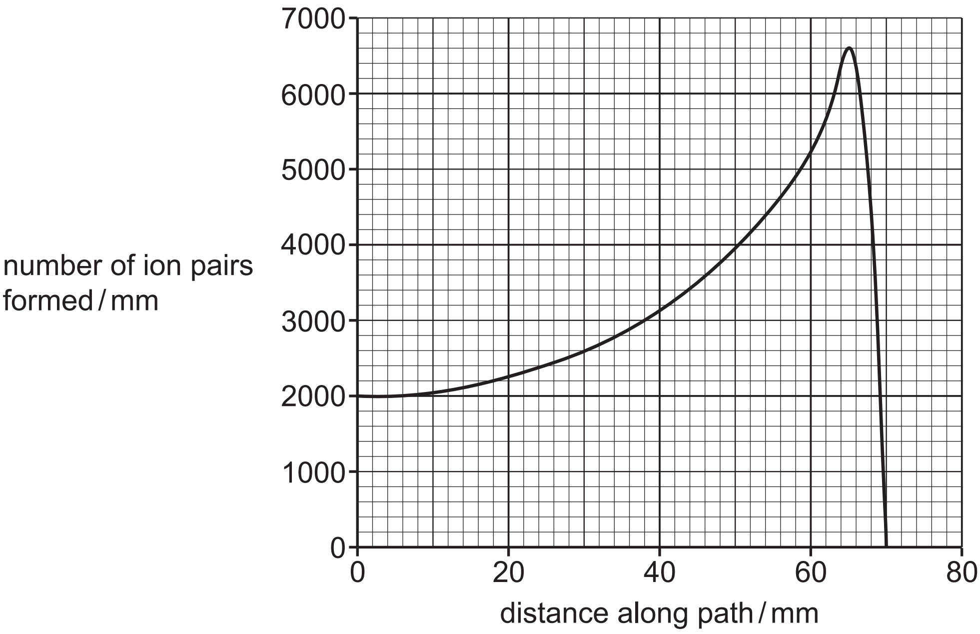

Fig. 5.1

(a) (i) State how the graph shows that an alpha particle produces about 240 000 ion pairs along its track.

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.... **[1]**

(ii) It takes about 30 eV to produce an ion-pair. Estimate the kinetic energy of the alpha particle when it is ejected from a nucleus. Explain your reasoning.

Reasoning: ....

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kinetic energy = ... MeV **[2]**

(iii) Explain why beta particles have a longer range in air than alpha particles of the same initial energy.

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.... **[2]**

(b) **(i)** $^{224}_{88}\text{Ra}$ (radium-224) is an alpha emitter that can be used in radiotherapy. It decays as shown:

$$^{224}_{88}\text{Ra} \longrightarrow \,^{220}_{86}\text{Rn} + \,^{4}_{2}\text{He}$$

Assuming that the radium nucleus is stationary when it emits an alpha particle, use the principle of conservation of momentum to calculate the percentage of the kinetic energy released in the decay transferred to the alpha particle.

proportion of kinetic energy transferred to alpha particle = ... % **[2]**

(ii) Alpha emitters can be implanted into body tissue. The range of alpha particles in the tissue is typically about 0.1 mm.

State why the range is smaller in tissue than in air.

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.... **[1]**

(iii)* Use the data below to calculate the energy of an alpha particle released when a nucleus of radium decays. Use this figure to calculate the effective dose delivered to a group of cells of total mass 0.004 kg over two hours, a period much shorter than the half-life of radium. State and explain any assumptions you make in the calculation and whether you think they are reasonable.

mass of radium nucleus = 223.97191 u

mass of radon nucleus = 219.9642 u

mass of alpha particle = 4.00150 u

quality factor of alpha radiation = 20

activity of alpha source = 18 kBq

density of tissue = 990 kg m^{-3}

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.... **[6]**

6 **Fig. 6.1** shows wavefronts produced by a very small object. The wavefronts are approaching a converging lens.

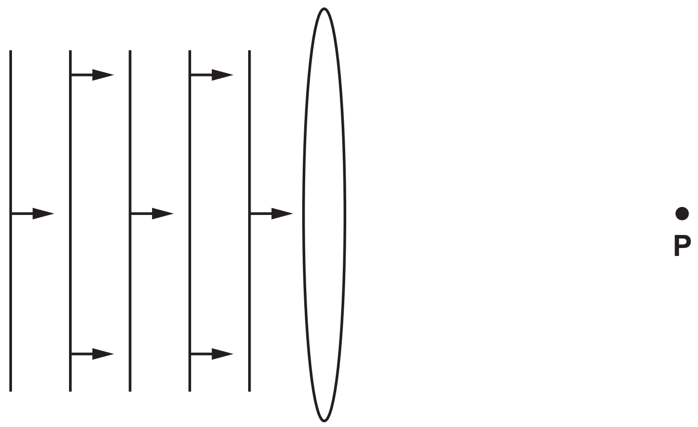

Fig. 6.1

(a) **(i)** What feature of **Fig. 6.1** shows that the object producing the wavefronts is a long way from the lens?

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.... **[1]**

(ii) Add wavefronts to the right of the lens which focus at point P.

[1]

(iii) The lens adds curvature of +1.8 D to the waves. Calculate the distance from the lens to point P. Explain your reasoning.

distance to P = ... m

Reasoning: ....

.... **[2]**

(b) Simple lenses can produce chromatic aberration, resulting in different lens-powers for different colours. This happens because different wavelengths of light travel through glass at different speeds.

(i) Complete the table below of the refractive index from air to glass for different wavelengths of light.

velocity of all wavelengths in air = $3.00 \times 10^8\,\text{m}\,\text{s}^{-1}$

wavelength / nm	**velocity of light in glass / $\text{m}\,\text{s}^{-1}$**	**refractive index**
410	$1.81 \times 10^8\,\text{m}\,\text{s}^{-1}$	
710		1.62

[2]

(ii) Explain why the power of the lens will be greater for shorter wavelength light and the effect this will have on the focal length of the lens for light of different wavelengths.

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.... **[2]**

(c) **Fig. 6.2** shows a highly simplified diagram of the eye.

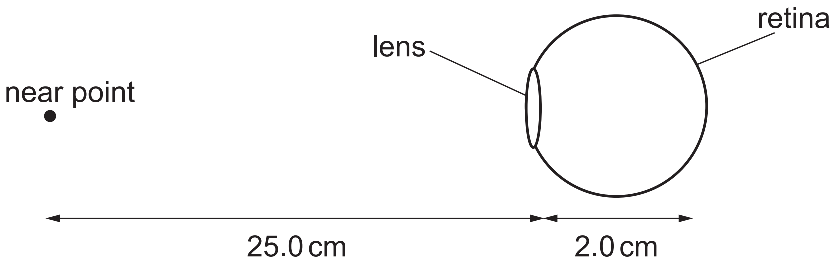

Fig. 6.2 (not to scale)

The distance between the lens and the retina, the surface on which the image is formed, is 2.0 cm.

The curvature of the eye lens increases as it focuses on nearby objects. The nearest point an object can be brought to focus by a person with normal vision is 25 cm. This is called the near-point.

(i) This letter **X** is approximately 4 mm high. Calculate the height of the image of the **X** on the retina of a person with normal vision when viewed from the near point of 25 cm.

image height = ... m **[2]**

If an individual is unable to focus as close as 25 cm they can use a converging lens to bring the image into focus.

(ii) Calculate the power of a lens required to allow a person with a near point of 50 cm to focus an object at a distance of 25 cm.

lens power = ... D **[2]**

(d) Here are some data about two materials used for spectacle lenses.

material	**density / $kg\,m^{-3}$**	**refractive index**
high-index glass	3.2×10^3	1.70
plastic (polycarbonate)	1.2×10^3	1.59

Explain why high-index glass might be chosen for more powerful spectacle lenses whereas polycarbonate might be a better choice for lower power lenses. Make your reasoning clear.

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.... **[3]**

SECTION C

This section is based on the **Advance Notice Article**.

7 This question is about a simple generator (lines 19–27). **Fig. 7** shows how the flux through a square coil varies with time as the coil rotates in a uniform magnetic field.

The emf ε generated is given by the equation

ε = maximum flux linkage × $2\pi f\sin(2\pi ft)$

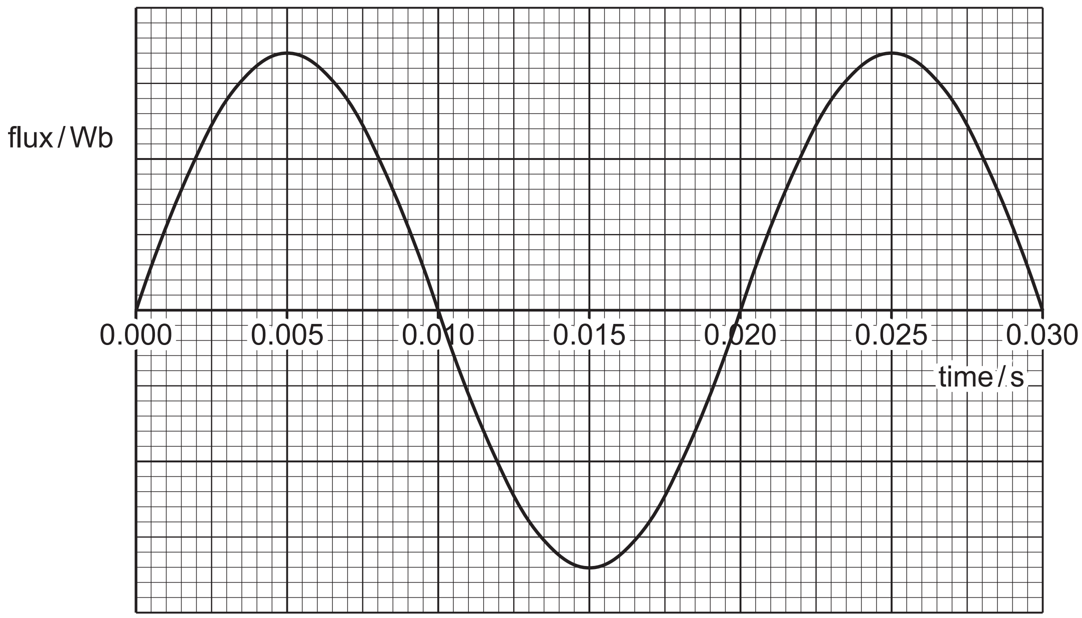

Fig. 7

The maximum e.m.f. induced in the coil is 24.0 V.

(a) **(i)** Calculate the maximum flux linkage in the coil.

maximum flux linkage = ... Wb turns **[2]**

(ii) The coil has sides of length 12 cm. It has 400 turns. Calculate the flux density *B* of the magnetic field.

flux density *B* = ... T **[2]**

(b) Suggest and explain two modifications to the generator that would increase the e.m.f. induced without changing the frequency of the rotor. You may refer to equations in your explanations.

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.... **[4]**

8 This question is about the output power from a wind farm (lines 29–41).

(a) Use the concept of the kinetic energy of a volume of air moving with velocity v to show that the power of the wind striking area A is given by

$$P = \frac{1}{2}\rho A v^3$$

where ρ is the density of the air.

[2]

(b)* Here are some data about a wind farm:

efficiency = 43%
turbine height = 90 m
blade diameter = 120 m
number of turbines = 85
density of air = 1.2 kg m^{-3}
output power = 900 MW.

Use the data above and the equations in the article to estimate the wind speed at a height of 10 m required to produce this power. Explain your method.

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wind speed = ... m s^{-1} **[6]**

9 This question is about a small hydroelectric turbine. Water flows down a penstock from a head height of 195 m. (See Figs 4 and 5 in the article.)

The output power of the turbine is 94.5 kW.
Flow rate of water = 55 kg s^{-1}.

(a) Calculate the efficiency at which the potential energy of the water is transferred to energy output.

efficiency = ... % **[2]**

(b) (i) Consider water flowing from a pipe of cross-sectional area 7.9×10^{-3} m^2.

Water flows out of the pipe at a rate of 55×10^{-3} $m^3 s^{-1}$. Show that the velocity of the water leaving the pipe is about 7 m s^{-1}.

[1]

The water strikes a surface and divides as shown in **Fig. 9**. The horizontal velocity of the water reduces to zero when it strikes the surface.

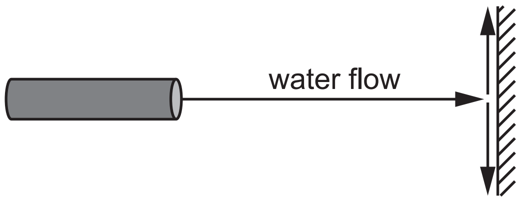

Fig. 9

(ii) Calculate the magnitude of the force exerted on the surface.

density of water = 1000 kg m^{-3}

force = ... N **[2]**

(iii) Maximum power is extracted from a Pelton turbine when the velocity of the turbine vane is half that of the water jet.

Calculate the maximum power that can be transferred to the generator when the water in the situation described in **(b)(i)** strikes a surface moving to the right with a velocity of $3.5\,\mathrm{m\,s^{-1}}$.

power = ... W **[2]**

(iv) Describe and explain how the design of the vane increases the power output of the Pelton turbine (see **Fig. 7** in the article).

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.... **[4]**

END OF QUESTION PAPER

ADDITIONAL ANSWER SPACE

If additional space is required, you should use the following lined page(s). The question number(s) must be clearly shown in the margin(s).